



Prediction of a new result for the "twin paradox" experiment, consistent with the time-energy relationship

Denis Michel

► To cite this version:

Denis Michel. Prediction of a new result for the "twin paradox" experiment, consistent with the time-energy relationship. 2015. hal-01182589v2

HAL Id: hal-01182589

<https://hal.science/hal-01182589v2>

Preprint submitted on 31 Aug 2015 (v2), last revised 21 Dec 2022 (v4)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Prediction of a new result for the "twin paradox" experiment, consistent with the time-energy relationship

Denis Michel

Universite de Rennes1. Campus de Beaulieu Bat. 13. 35042 Rennes France. denis.michel@live.fr

Abstract

A new result is proposed for the time dilation effect of the round trip, known as the twin paradox thought experiment. This differential ageing effect has strangely been treated in general relativity in absence of gravity and in special relativity in absence of uniform motion, which misleadingly inspired the idea of paradox. The alternative Doppler treatment proposed here reveals a new solution unrelated to the Lorentz dilation factor. This solution is then shown consistent with the general time-energy relationship which applies to all cases of time distortion, including special relativity, gravity and cosmological expansion.

1 Introduction

Apparent time dilation corresponds to wavelength increase, or equivalently frequency decrease. This phenomenon is particularly obvious for distant supernovae whose large redshift (for example $\lambda^{\text{app}}/\lambda = 1.5$), precisely coincides with an increased duration of brightness (1.5-fold longer in the example) [1]. In special relativity (uniform motions), a time interval corresponds to a given number of periods (say n) so that $\Delta t' > \Delta t$ is equivalent to $nT' > nT$ and to $\nu' < \nu$. In other words, wave distortion exactly compensates spacetime distortion in such a way that (i) the speed of light and (ii) the number of periods, are both maintained identical for all observers [2]. In addition in the twin paradox, following the idea of Darwin [3], there is a difference in the number of periods. This phenomenon generates a new differential ageing effect irrespective of the Doppler formula used, showing that it is not specifically a matter of special relativity. Finally, the time-energy relationship is shown to predict and unify all the types of time distortion.

2 The twin experiment

Contrary to special relativity in which all the frames are uniformly moving, in the famous twin paradox, the

symmetry of special relativity is broken by the moving twin, even he flies at constant speed. Einstein himself was troubled by the consequences of his own work. He first explained the experience of half-turn of a clock using the time dilation of special relativity [6]. Later, he attributed the asymmetry between the clocks to a pseudo-gravitational effect of the about turn [7]. However, atomic clocks have been shown insensitive to acceleration [5]. In fact as suggested below, the result of this experiment does not require the relativity theory and can be found using the classical Doppler equation. The wrong treatment of the twin experiment would be to use special relativity tools (which hold exclusively for inertial frames) and to arbitrarily decide who travels and who remains at rest. This can be readily shown: Twin brothers are separated; one of them remains inert while the other crosses a distance dl before joining his brother. As they started from the same point and arrived to the same point of spacetime, if one decides that it is the twin whose proper time is labelled t' who travels,

$$ds^2 = (cdt)^2 = (cdt')^2 - dl^2 \quad (1a)$$

with $v = dl/dt'$, one obtains the traditional time dilation result $dt'/dt = 1/\sqrt{1 - v^2/c^2}$, and conversely if it is the other twin (of proper time t) who travels,

$$ds^2 = (cdt)^2 - dl^2 = (cdt')^2 \quad (1b)$$

with $v = dl/dt$, $dt/dt' = 1/\sqrt{1 - v^2/c^2}$. Hence, it is impossible to break the symmetry. No physical experiment can measure the absolute velocity of a frame with a uniform motion in which it is conducted, so that one can not assign the speed v specifically to one twin. This problem is at the origin of the term paradox, but now most authors point that in fact, the moving twin does not remain in a single inertial frame since his motion is not uniform, and certain authors recourse to general relativity to treat this situation. Many resolutions of this actively debated experiment have already been described in the context of either special or general relativity. The most frequently reported result is that upon arrival, the clock of the travelling twin delays relative to that of the resting twin in the ratio $\sqrt{1 - v^2/c^2}$ [3, 4, 5], for example

0.8 for a travel at a speed of $0.6 c$ [4]. A different result is proposed here. To simplify the treatment, let us consider a collinear round trip (starting from a spatial station to eliminate a role for gravity). When located at a distance D from his sedentary brother, the travelling twin makes an about-turn at constant speed and infinite acceleration (like a frontal elastic collision). The twins continuously exchange light pulses with the same fundamental wavelength at the origin. Viewed by the travelling twin, things are very simple. He perceives instantaneously his about-turn and sees a dilated Doppler effect from his resting brother before his turn-around and a shrunk Doppler effect during the trip back. Viewed by the resting twin, things seem simple in appearance but are less simple in reality because as explained in [3], he cannot perceive the change of Doppler effect during the turn because light emitted at this point takes a time D/c to reach him, so that when he perceives it, the travelling twin has already crossed $d = vD/c$ towards him. The switch between the blue and red shifts does not occur at D but at $D + d$, or $D(1 + \frac{v}{c})$. This mere fact explains why the number of pulses received by the twins is not symmetrical. Hence, the twin paradox can not help dis-

tinguishing between the relativistic and classical Doppler effects. The number of wave crests received by the inert twin is lower than that received by the travelling twin, which means that the symmetry is broken contrary to special relativity in which the number of pulses is the same for all observers.

In the numerous debates on the twin paradox, a frequent argument against the followers of general relativity is that the phase of acceleration or pseudo-gravity can be as short as desired compared to the duration of the trip. We see in the mechanism described here that this phase can indeed be reduced to zero in an instantaneous about-turn like an elastic collision, but the time period of asymmetry remains equal to the fraction v/c of the trip. For his demonstration, Darwin used the relativistic Doppler equation and the arithmetic mean [3]. The arithmetic and geometric modes of averaging will be tested here with different Doppler equations. The result will be shown independent on the Doppler equation used. Since the geometric mean is more appropriate for averaging simultaneously wavelengths and frequencies, it will be used first.

Table 1: Mean wavelength averaged over the whole round trip, perceived by the resting (R) and travelling (T) twins and calculated using different Doppler formulas. All of them give the same ratio of wavelength exchanged during the round trip.

Point of view	Classical	Relativistic	Conjectural
Traveller $\left\langle \frac{\lambda_{RT}^{app}}{\lambda} \right\rangle$	$\sqrt{1 - \frac{v^2}{c^2}}$	1	$1/\sqrt{1 - \frac{v^2}{c^2}}$
Inert $\left\langle \frac{\lambda_{TR}^{app}}{\lambda} \right\rangle$	$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}} \sqrt{1 - \frac{v^2}{c^2}}$	$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}}$	$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}} / \sqrt{1 - \frac{v^2}{c^2}}$
Ratio $\frac{\langle \lambda_{TR}^{app} \rangle}{\langle \lambda_{RT}^{app} \rangle}$	$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}}$	$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}}$	$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}}$

2.1 Wavelength geometric averaging

λ_{RT}^{app} is the wavelength of the resting source viewed by the traveller and λ_{TR}^{app} is the wavelength of the travelling source viewed by the resting twin. The asymmetry between the twins will be evaluated using either the classical, the relativistic, or the conjectural [2] Doppler formulas, on the basis that the Doppler effects perceived by the resting twin is dilated during the $(1 + \frac{v}{c})$ th of the journey and is shrunk during the $(1 - \frac{v}{c})$ th of the journey. Wavelengths can be averaged geometrically over the whole trip as follows.

2.1.1 Home clock perceived by the traveller

Using the classical Doppler formula,

$$\left\langle \frac{\lambda_{RT}^{app}}{\lambda} \right\rangle = \left(\left(1 + \frac{v}{c} \right) \left(1 - \frac{v}{c} \right) \right)^{\frac{1}{2}} = \left(1 - \frac{v^2}{c^2} \right)^{\frac{1}{2}} \quad (2)$$

with the relativistic Doppler formula,

$$\left\langle \frac{\lambda_{RT}^{app}}{\lambda} \right\rangle = \left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \sqrt{\frac{1 - \frac{v}{c}}{1 + \frac{v}{c}}} \right)^{\frac{1}{2}} = 1 \quad (3)$$

and using the conjectural Doppler formula,

$$\left\langle \frac{\lambda_{RT}^{app}}{\lambda} \right\rangle = \left(\left(1 + \frac{v}{c} \right) \left(1 - \frac{v}{c} \right) \right)^{-\frac{1}{2}} = \left(1 - \frac{v^2}{c^2} \right)^{-\frac{1}{2}} \quad (4)$$

2.1.2 Traveller's clock perceived by the resting brother

Using the classical Doppler formula,

$$\begin{aligned} \left\langle \frac{\lambda_{TR}^{app}}{\lambda} \right\rangle &= \left(\left(1 + \frac{v}{c} \right)^{(1+\frac{v}{c})} \left(1 - \frac{v}{c} \right)^{(1-\frac{v}{c})} \right)^{\frac{1}{2}} \\ &= \left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right)^{v/2c} \left(1 - \frac{v^2}{c^2} \right)^{\frac{1}{2}} \end{aligned} \quad (5)$$

with the relativistic Doppler formula,

$$\begin{aligned} \left\langle \frac{\lambda_{TR}^{app}}{\lambda} \right\rangle &= \left(\left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right)^{(1+\frac{v}{c})} \left(\frac{1 - \frac{v}{c}}{1 + \frac{v}{c}} \right)^{(1-\frac{v}{c})} \right)^{\frac{1}{4}} \\ &= \left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right)^{v/2c} \end{aligned} \quad (6)$$

and using the conjectural Doppler formula,

$$\begin{aligned} \left\langle \frac{\lambda_{TR}^{app}}{\lambda} \right\rangle &= \left(\left(1 - \frac{v}{c} \right)^{(1+\frac{v}{c})} \left(1 + \frac{v}{c} \right)^{(1-\frac{v}{c})} \right)^{-\frac{1}{2}} \\ &= \left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right)^{v/2c} \left(1 - \frac{v^2}{c^2} \right)^{-\frac{1}{2}} \end{aligned} \quad (7)$$

These results are summarized in Table.1.

The ageing ratio between the travelling and resting clocks is $\sqrt{((c+v)/(c-v))^{v/c}}$, regardless of the Doppler formula used, relativistic or not. Interestingly using the geometric mean, the reciprocal time dilation effect of

special relativity completely disappears with the relativistic Doppler equation, but not with the conjectural equation (Table.1). The result calculated here is not the time dilation factor generally reported in the literature [4]. Anecdotaly, this result can be written e^{vw/c^2} , an elegant combination of velocity v and of hyperbolic rapidity $w = c \tanh^{-1}(v/c)$.

2.2 Arithmetic mean frequency

Apparent temporal paradoxes often disappear if conceiving time as a frequency depending on the energetic status of the system. Frequencies provide a very intuitive idea of time when applied for example to heart beats, days and seasons. As stated above, the appropriate tool for averaging both wavelengths and frequencies is the geometric mean, but the traditional arithmetic mode of averaging gives very similar results for frequencies. The arithmetic mean frequency $\langle \nu \rangle$ of the pulses exchanged during a trip composed of different stages A and B of homogeneous frequencies, is

$$\langle \nu^{app} \rangle = \frac{D_A}{D} \nu_A + \frac{D_B}{D} \nu_B \quad (8)$$

The two phases perceived by the travelling twin are $D_A = D_B = D$, and for the resting twin, as explained above, $D_A = (1 + \frac{v}{c}) D$ and $D_B = (1 - \frac{v}{c}) D$. Using the three previously used Doppler equations, Eq.(8) gives the results compiled in Table.2.

Table 2: Arithmetic mean frequency averaged over the whole round trip, perceived by the resting (R) and travelling (T) twins and calculated using different Doppler formulas.

Point of view	Classical	Relativistic	Conjectural
Traveller $\left\langle \frac{\nu_{RT}^{app}}{\nu} \right\rangle$	$\frac{1}{1 - \frac{v^2}{c^2}}$	$\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$	1
Inert $\left\langle \frac{\nu_{TR}^{app}}{\nu} \right\rangle$	1	$\sqrt{1 - \frac{v^2}{c^2}}$	$1 - \frac{v^2}{c^2}$
Ratio $\frac{\left\langle \nu_{RT}^{app} \right\rangle}{\left\langle \nu_{TR}^{app} \right\rangle}$	$\frac{1}{1 - \frac{v^2}{c^2}}$	$\frac{1}{1 - \frac{v^2}{c^2}}$	$\frac{1}{1 - \frac{v^2}{c^2}}$

Once again, the three Doppler formulas give the same result, close to the previous one.

Result: A round-trip traveller aged

$$\left(\sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \right)^{\frac{v}{c}} \sim \frac{1}{1 - \frac{v^2}{c^2}}$$

times slower than his resting counterpart who stayed at home. This result is greater by about $\frac{1}{2} \frac{v^2}{c^2}$ than the currently admitted ageing ratio of $1/\sqrt{1 - \frac{v^2}{c^2}}$.

3 Shortcut verifications with energy

The objective of this section is twofold: (i) verify the previous result through a different approach and (ii) generalize the correspondence between waves and time distortions to all other situations.

3.1 The energetic connection of time and wavelengths

Following the Planck/Einstein relationship $E = h\nu$, frequency is energy. After showing identical equations for energy and frequencies, Einstein concluded that frequency and energy vary with the same law with the state of motion of the observer [6]. This correspondence is in fact natural with respect to the quantum of time. Indeed, in the principle of uncertainty $\Delta E \Delta t \geq h/4\pi$, the energetic component can be expressed as $\Delta E = h\Delta\nu$, which gives $\Delta t \Delta\nu \geq 1/4\pi$, showing that time and frequencies are mutually constrained. This relationship allows to simply predict Doppler effects if assuming mass conservation.

3.2 Mass conservation

According to everyday experience, the mass of clocks (travelling inside rockets), will be supposed unchanged upon arrival. This assumption avoids an internal contradiction in special relativity pointed by de Broglie: A change of frame predicts a change of energy, from $E_0 = m_0 c^2$ to $E^{\text{mov}} = m_0 c^2 / \sqrt{1 - \frac{v^2}{c^2}}$ and then to a change of frequency $\nu^{\text{mov}} = E^{\text{mov}}/h = m_0 c^2 / h \sqrt{1 - \frac{v^2}{c^2}} = \nu_0 / \sqrt{1 - \frac{v^2}{c^2}}$. This result is inverse to that expected from a time dilation perspective. To plug this breach, de Broglie developed a complex theory called "harmony of the phases" with phase speeds higher than c [8]. As these phases have not been evidenced yet and for simplicity, mass effects will be prudently considered negligible here.

3.3 The twin experiment

The total energy of the inert twin is its resting energy $E = mc^2$. During his round trip, his brother first jumps in a new frame moving at speed v relative to the starting one, and then jumps back to his initial frame. The round trip (rt) frequency follows

$$\frac{\nu^{\text{rt}}}{\nu} = \frac{E^{\text{rt}}}{E} = \frac{E - \Delta E_{\text{jumps}}}{E} \quad (9a)$$

with

$$\Delta E_{\text{jumps}} = \frac{1}{2}mv^2 + \frac{1}{2}m(-v)^2 = mv^2 \quad (9b)$$

which gives

$$\frac{\nu^{\text{rt}}}{\nu} = \frac{mc^2 - mv^2}{mc^2} = 1 - \frac{v^2}{c^2} \quad (9c)$$

so that

$$\frac{\lambda^{\text{rt}}}{\lambda} = \frac{1}{1 - \frac{v^2}{c^2}} \sim \left(\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right)^{v/2c} \quad (9d)$$

The two approaches (Doppler and energy) give the same result.

3.4 Uniform motion

The total energy of an inert clock is its resting energy $E = mc^2$. Starting from this frame, a clock jumping to an other frame at speed v , has to consume a kinetic energy such that

$$\frac{\nu^{\text{mov}}}{\nu} = \frac{E - \Delta E_{\text{jump}}}{E} = \frac{mc^2 - \frac{1}{2}mv^2}{mc^2} = 1 - \frac{1}{2} \frac{v^2}{c^2} \quad (10)$$

The time dilation of special relativity is recovered:

$$\frac{\lambda^{\text{mov}}}{\lambda} = \frac{1}{1 - \frac{1}{2} \frac{v^2}{c^2}} \approx \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (11)$$

3.5 Uniform acceleration

Suppose that two objects A and B of identical masses m , are submitted to a uniform acceleration field γ shaping the whole space and that B is shifted in this field at a distance d from A . The potential energy of B has decreased compared to that of A

$$\frac{\nu^B}{\nu^A} = \frac{E^B}{E^A} = \frac{E^A - \Delta E}{E^A} \quad (12)$$

with

$$\Delta E = \frac{1}{2}mv_B^2 - \frac{1}{2}mv_A^2 = \frac{1}{2}m(v_B^2 - v_A^2) \quad (13)$$

This value is given by the Newtonian rules of uniform acceleration:

$$v_B = v_A + \gamma t \quad (14)$$

and

$$d = v_A t + \frac{1}{2} \gamma t^2 \quad (15)$$

By eliminating the variable t between these two equations, one obtains

$$v_B^2 - v_A^2 = 2\gamma d \quad (16)$$

As it is impossible to get out of the space-wide acceleration field, the farthest object A will be arbitrarily considered as the reference one and Eq(12) finally gives

$$\frac{\nu^B}{\nu^A} = \frac{mc^2 - m\gamma d}{mc^2} = 1 - \frac{\gamma d}{c^2} \quad (17)$$

This formula is sometimes adapted to the gravitational redshift by considering γ as a gravitational acceleration $\gamma = g = GM/r^2$ where G is the gravitational constant, r is the radial distance between the source and the center of a gravitating body of mass M . But this treatment ignores that a gravitational free fall is not uniform but is an accelerated acceleration, as detailed later.

3.6 Gravitational redshift

3.6.1 Loss of gravitational potential

An object trapped in a gravitational well should consume energy to escape it, because of its loss of potential gravitational energy (GMm/r), compared to an identical mass located very far from the well,

$$\frac{\nu^{\text{gr}}}{\nu} = \frac{E - \Delta E_{\text{gr}}}{E} \quad (18a)$$

$$\frac{\nu^{\text{gr}}}{\nu} = \frac{mc^2 - mGM/r}{mc^2} = 1 - \frac{GM}{rc^2} \quad (18b)$$

Using series expansions near zero,

$$\frac{\lambda^{\text{gr}}}{\lambda} \approx 1 + \frac{GM}{rc^2} \approx \frac{1}{\sqrt{1 - \frac{2GM}{rc^2}}} \quad (18c)$$

known as the redshift of Einstein.

3.6.2 Accelerated gravitational acceleration

Gravity (g) is not an uniform acceleration field but is inversely proportional to the square of the distance r from the center of the gravitating mass M ($g = GM/r^2$). Hence, a free fall in vacuum towards a massive body is an "accelerated acceleration". The distance $x(t)$ crossed by an inert body jumping at $t_0 = 0$ from an altitude a ($v_a = 0$), follows

$$\frac{dx}{dt} = GM \frac{t}{(a-x)^2} \quad (19)$$

with the initial condition $x(0) = 0$. Based on this equation, the distance between the jumper and the center of gravity $r = a - x$, decreases with time according to

$$r(t) = \sqrt[3]{a^3 - \frac{3}{2}GMt^2} \quad (20)$$

and when r reaches the altitude b ($< a$), the speed is $v_b = \gamma_b t_b + v_a$ where t_b is obtained with Eq.(20) and γ_b is deduced from Eq.(19),

$$v_b = \frac{1}{b^2} \sqrt{\frac{2}{3}GM(a^3 - b^3)} \quad (21)$$

which implies a drop of potential energy of the same amount, generating a redshift of a source B (at altitude b) perceived by a receiver A (at altitude a), of

$$\frac{\nu^B}{\nu^A} = 1 - \frac{GM}{3c^2} \frac{a^3 - b^3}{b^4} \quad (22)$$

This gravitational redshift between two objects in the same well is not an absolute value but depends on the relative altitude of the source and the receiver. If both are at the same distance from the massive object ($a = b$), no shift is detected. The usual treatments of the gravitational redshift using Eq.(17) with $\gamma = GM/r^2$, yields different results. The comparison with the present treatment gives the following value to r :

$$r = b^2 \sqrt{3 \frac{a-b}{a^3-b^3}} \quad (23)$$

which shows that the two approaches are equivalent only for $r = a = b$, that is to say without jump. The virtual radius r is in fact lower than b , because the free fall is an accelerated acceleration. This overlooked property forbids coupling Eq.(17) to $\gamma = GM/r^2$.

3.7 The cosmological redshift

Even before the publication of Hubble [9], Lemaître had shown that wavelengths should follow expansion [10]. For an interval of universe

$$ds^2 = dt^2 - a(t)^2 d\sigma^2 \quad (24)$$

where $d\sigma$ is the element length of a space of radius equal to 1, the equation of a light beam is

$$\sigma_2 - \sigma_1 = \int_{t_1}^{t_2} \frac{dt}{a} \quad (25)$$

where σ_1 and σ_2 are the coordinates of a source and an observer. A beam emitted later at $t_1 + \delta t_1$ and arriving at $t_2 + \delta t_2$ undergoes a shift such that

$$\frac{\delta t_2}{a_2} - \frac{\delta t_1}{a_1} = 0 \quad (26)$$

giving

$$z = \frac{\delta t_2}{\delta t_1} - 1 = \frac{a_2}{a_1} - 1 \quad (27)$$

where δt_1 and δt_2 can be considered as the periods at emission and reception respectively [10]. If a procession of walkers regularly spaced crosses a stretching rubber band, on arrival their spacing will obviously be stretched in the same ratio as the rubber band. The same reasoning holds for a series of wave crests. In his article, Lemaître called this effect a Doppler effect [10]. This term is acceptable if broadly defining the Doppler effect as a wave distortion, but this is not the classical Doppler effect related to the speed of the source. The ratio between the

reception and emission wavelengths simply follows the increase of the distance D between the source and the receiver, which took place during the travel of light:

$$\frac{\Delta t^{\text{app}}}{\Delta t} = \frac{T^{\text{app}}}{T} = \frac{D_{\text{reception}}}{D_{\text{emission}}} \quad (28)$$

This redshift is exclusively a phenomenon of wave distortion, holding even if the sources and the receiver belong to the same inertial frame. The association between the redshift and the duration [1], is the ultimate proof of the connection between time and wavelength distortion. The connection with energy is less obvious than for the previous examples of time distortion, but exists when considering the relationship between space and energy. The uncertainty principle links space and momentum in $\Delta x \Delta p \geq h/4\pi$, where $p = E/c$. Hence, $\Delta E \geq hc/4\pi \Delta x$. Stretching x implies a decrease of E to maintain this fundamental relationship.

4 Conclusion

Strangely, the popular twin paradox is sometimes considered as a verification of the time dilation of special relativity, whereas special relativity deals only with uniform motion. Doppler analyses predict different time distortion effects depending on whether the moving source only passes near the receiver or starts from the receiver frame and returns to its point of origin. The symmetrical time dilation of special relativity based on the size of time units, is radically different from the non-symmetrical time dilation of the twin paradox based on the number of time units. The twin thought experiment mixes (i) a traditional Doppler effect stretching and then shortening the standard wavelength and (ii) a shift in the perception of the about-turn. The new solution of the twin experiment obtained here in different ways, differs from the classical result that is built on the Lorentz dilation factor. In practice, both formulas give similar but possibly testable results. This new solution is based on the conception of time as a frequency depending on the energetic status of the system and its validity is supported by the general energetic approach to wavelength and time

distortion effects in all fields of physics. This theoretical prediction is submitted to future precise experimental tests, in particular to distinguish the difference of $v^2/2c^2$ with the classically admitted result.

References

- [1] Perlmutter, S. Supernovae, dark energy, and the accelerating universe: The status of the cosmological parameters. Proceedings of the XIX International Symposium on Lepton and Photon Interactions at High Energies. Stanford, California, 1999.
- [2] Michel, D. 2015. Slowing time by stretching the waves in special relativity. <https://hal.archives-ouvertes.fr/hal-01097004v6/document>
- [3] Darwin, C.G. 1957. The clock paradox in relativity. *Nature* 180, 976-977.
- [4] Lasky, R.C. 2012. Time and the twin paradox. *Sci. Am.* 16, 21-23.
- [5] Lämmerzhall, C. 2005. Special relativity and Lorentz invariance. *Ann. Phys.* 14, 71-102.
- [6] Einstein, A. 1905. Zur Elektrodynamik bewegter Körper (On the electrodynamics of moving bodies) *Annal. Phys.* 17, 891-921.
- [7] Einstein, A. 1918. Dialog über Einwände gegen die Relativitätstheorie. *Die Naturwissenschaften*.
- [8] de Broglie, L. Recherches sur la théorie des quanta. Thèse de physique. Paris, 1924.
- [9] Hubble, E. 1929. A relation between distance and radial velocity among extra-galactic nebulae. *Pnas* 15, 168-173.
- [10] Lemaître G. 1927. Un Univers homogène de masse constante et de rayon croissant rendant compte de la vitesse radiale des nébuleuses extra-galactiques. *Annal. Soc. Sci. Bruxelles.* A47, 49-59.